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MAGNETO-IONIC CONTROL OF INTERFACIAL MAGNETISM

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Voltage control of magnetism has the potential to substantially reduce power consumption in spintronic memory and logic devices, while offering new functionalities through field-effect operation [1-4]. Magneto-electric coupling has most often been achieved using complex oxides such as ferroelectrics, piezoelectrics, or multiferroic materials. Here I describe a new approach to voltage control of magnetism based on solid-state electrochemical switching of the interfacial oxidation state [2-4] in thin metallic ferromagnets. In ultrathin ferromagnet/oxide bilayers, strong perpendicular magnetic anisotropy (PMA) often arises from arises from interfacial hybridization between the ferromagnetic metal and oxygen ions. By using a solid-state ionic conductor with high oxygen ion mobility as a gate oxide, we show that one can electrically displace O^{2-} at the ferromagnet/oxide interface to achieve extremely large changes in interfacial PMA [4]. This magneto-ionic coupling allows for nonvolatile switching of interfacial magnetic properties to an extent never before achieved in conventional magneto-electric devices [2-4]. I will describe our work on Co/GdO_x bilayers [2-4], in which GdO_x acts as a gate oxide that permits efficient oxygen exchange. We study Ta(4 nm)/Pt(3 nm)/Co(0.9 nm)/GdO_x(3nm) thin-film stacks on Si, in which the thin Co layer exhibits strong PMA in the as-grown state. We present high-resolution cross-sectional transmission electron microscopy (TEM) and electron energy-loss spectroscopy (EELS) performed in-situ during bias application [4], which directly reveals the reversible motion of oxygen ions at the Co/GdO_x interface. This nonvolatile switching of interfacial oxygen stoichiometry gives rise to an unprecedentedly large change in interfacial PMA by more than 0.75 erg/cm^2 [4], which can be toggled repeatedly by reversing the bias polarity. We show that by optimizing the device structure and geometry, these effects can be achieved at room temperature and that the switching speeds can be reduced from 100s of seconds [2-4] to 100s of microseconds [4], and describe approaches to further enhance the device response. Finally, we describe the integration of magneto-ionic gates into spintronic devices based on the controlled motion of magnetic domain walls in magnetic nanowires, which function as low-power spintronic memory and logic devices. In collaboration with U. Bauer, A. J. Tan, P. Agrawal, S. Emori, and H. L. Tuller at MIT and L. Yao and S. van Dijken, at Aalto Univ. Supported by NSF ECCS-1128439, the NSF MRSEC Program under DMR-0819792, and the Samsung Global MRAM Innovation Program.

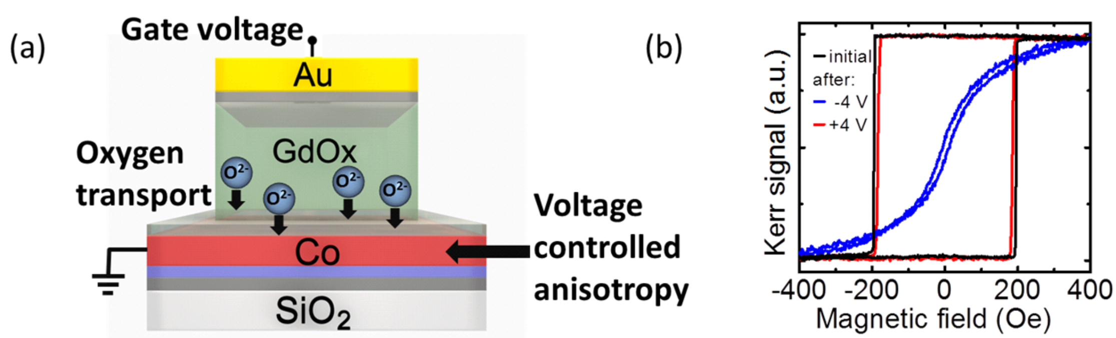

Figure 1 – (a) Schematic of magneto-ionic device allowing voltage control of interface anisotropy in thin (0.9 nm) Co layer through electric field driven O^{2-} displacement. (b) Out of plane hysteresis loops measured at zero bias in the initial state, after applying gate voltage V_g=-4 V, and after subsequently applying V_g=+4 V

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